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DETERMINING INPUT-OUTPUT RELATIONSHIPS IN MILK PRODUCTION

Feed Input and Milk Output
Preliminary Results

By

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DETERMINING INPUT-OUTPUT RELATIONSHIPS IN MILK PRODUCTION [1]

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In the application of economics to actual production problems, we are concerned not only with the question of whether certain elements of production should be used or not, whether to use machines or hand labor, tractors or horses, but also with the less dramatic question, How much of each cost factor should be used? How much does it pay to use?

The limits depend upon how the principle of diminishing returns applies to the problem at hand, upon how soon and how seriously we encounter its effects. These effects, physical and economic, permeate all production. The direction of economic affairs, be it in manufacturing or in farming, is constantly concerned with problems in this borderline field of technology and economics.

In the technical sciences the quest for accurate measurement is an old one. In many phases of economic theory, recent years have witnessed a shift from a purely qualitative to a quantitative basis. The theory is being confronted with the facts. This often reveals that although the theory is broadly applicable, the outcome is greatly at variance with prevailing views. The investigations in input-output relationships in milk production now in progress represent an attempt to accomplish quantitative verification of theory and to obtain data that will be useful to economists, technical specialists, and producers in determining the most economic organization and adjustment of production.

Dairy farming is one of the major types of farming and has experienced a steady and continued growth in importance. The economics of milk production therefore has naturally attracted the attention of agricultural economists. A number of attempts have been made to establish such economically important relationships as that between feed inputs and milk outputs in order to use them for economic analyses of the dairy enterprise. So far the attempts have taken the form of the well-known "statistical" studies. Usually these studies have tried to establish the relationship by statistical treatment of data obtained from farm survey records, dairy herd improvement records and supervised accounting records.[2] In the farm survey and cost route records only herd averages have been available and the findings have to be discounted to some extent due to the fact that it was not possible to measure differences in productivity of the herds. In all three types of records, data on feed inputs are likely to be inaccurate. Nevertheless, these investigations have produced valuable information, but the inconsistencies between different studies have not been fully explained. This has been due not to the methods employed but to the estimating difficulties involved in obtaining the original records.

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[1] Delivered as a paper at the Annual Meeting of the American Farm Economic Association, Philadelphia, Pennsylvania, December 28, 1939.

In recognition of this situation we have employed in our present investigation the experimental [3] method in an endeavor to obtain more reliable original data. The data are obtained by conducting experiments designed specifically with regard to the problem at hand.

It has been said, and truly so, that the determination of the basic physical relationships is not economics at all, but purely a technical problem. So are farm accounting and banking statistics. In these fields also and in many others the data are not likely to be in the form needed for economic analysis unless the work is planned and executed jointly by economists and technologists. Despite the fact that a very large amount of money and effort has gone into technical research in milk production for more than half a century, practically no data are available which bear upon the problem of whether the law of diminishing returns applies to the feeding of dairy cows, and if it does, what the production function is. These are the data which will permit us to determine the economic limit to intensity of feeding under different price conditions.

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[2] As examples of this type of study, the following publications may be listed: Ezekiel, M.J.B., McNall, P.E., and Morrison, F.B., Practices Responsible for Variation in Physical Requirements and Economic Cost of Milk Production on Wisconsin Dairy Farms. Wisconsin Research Bulletin 79, August 1927, Pond, G.A., and Ezekiel, Mordecai, Factors Affecting the Physical and Economic Cost of Butterfat Production in Pine County, Minn. Minn. Agr. Expt. Sta. Bul. 270, Dec. 1930. Johnson, S.E., Tretsven, J.O., Ezekiel, Mordecai and Wells, O.V., Organization, Feeding Methods and Other Practices Affecting Returns on Irrigated Dairy Farms in Western Montana, Mont. Agr. Expt. Sta. Bul. no. 264, June 1932. A number of other studies only available as unpublished theses have been made utilizing the same technique which was indicated in the early bulletin by H.R. Tolley, J.D. Black and M.J.B. Ezekiel, Input as Related to Output in Farm Organization and Cost-of-Production Studies, U.S.D.A., Bulletin no. 1277, 1924.

[3] In reality, the experimental method is also statistical. The observations obtained from the experiment must be subjected to statistical treatment in order to extract from them the information wanted, and to ascertain how reliable and consistent this information is.

The subject of dairy feeding is a very broad one. It takes in a great deal of territory in the fields of animal physiology and nutrition, plant physiology, agronomy, the production and conservation of crops, the construction of dairy barns, and organization of the work of feeding and caring for the dairy herd. Therefore it is understandable that the problem of economy and particularly intensity has received little attention after some quite useful rough approximations had been obtained at an early date.

The amount of feed needed to maintain cows has been established, and the "requirements" for milk production have been determined by numerous experiments, with cows fed such quantities of balanced rations as would keep them at uniform body weight. Thus, when all feed above maintenance was converted into milk and none into increased body weight, the technically most efficient production was obtained. It has been assumed that this rate of feeding would be the most economical, as a rule, and feeding standards have been worked out on the basis of these figures. Total milk produced has been divided by total feed consumed, and average feed input per unit of milk output has been computed. In this way the requirements of the accepted feeding standards were determined.

On the basis of this, the farmer has been advised how much to feed different cows yielding different amounts of milk and how to vary feed inputs according to weight of cow and fat content of milk in order to have his cows neither gain nor lose in weight.

It has been tacitly assumed in most technical computations that the same average relationship between milk output and feed input holds good when the feeding level is raised or lowered, or, in other words, the requirements for additional milk produced are unchanged. However, this problem of intensity of feeding is an entirely different one which requires for its solution a different set of data. The question is not one of how much to feed cows yielding different quantities of milk, but of how an individual dairy cow responds to increased and to reduced feeding. On this question there is a pronounced lack of experimental data and it is to this that our present research is directed.

The studies on which I am reporting today have been planned and are being conducted jointly by the Bureau of Agricultural Economics and the Bureau of Dairy Industry 4/ in cooperation with ten State agricultural experiment stations. 5/

4/ Mr. T. E. Woodward and Mr. R. H. Smith of the Bureau of Dairy Industry, U.S.D.A. have handled the technical part of the planning and supervision in cooperation with the State agricultural experiment stations.
5/ Those in Delaware, Maryland, Michigan, Mississippi, New Jersey, New York (Geneva), Pennsylvania, Indiana (Purdue), South Dakota, and Virginia.

At these stations we have had as many as 200 cows on experiment. The production of the cows in their previous lactation periods are known from the station's records. An estimate can therefore be made of the productivity of each animal used in the experiment assuming that they have all had an equal chance to demonstrate their ability to produce under similar conditions of good dairy practice. All milk produced and all feeds consumed are weighed every day. The feeds are fed separately to each individual animal. Manger partitions prevent cows from stealing feed from each other. What is not eaten is weighed back. Feeds and milk are analyzed, and all experimental work is handled in accordance with the best available technique under conditions approaching good farm practice. Reports are made weekly.

In one series of these experiments, the cows are fed rations which are computed in what may be called the scientific way - that is, strictly according to an accepted feeding standard. All animals are fed maintenance rations according to their weight, but production rations vary from as much as 30% below to 30% above the standard level. In another series the practical dairyman's feeding is approached more closely. The cows are left free to consume roughage "ad libitum". Only the grain ration is varied in proportion to milk produced so as to feed "1 to 2", "1 to 3", "1 to 4", "1 to 6" (one pound of grain for every two pounds of 4% milk, etc.). Some cows are fed only roughage.

In a third series the cows are grain-fed as heavily as it is possible under practical farm conditions, taking care that roughage consumption does not sink so low as to cause mineral and vitamin deficiencies and endanger the health of the animals.

It was decided that in order to ascertain the full effects of changes in intensity of feeding, it would be necessary to have the experiments extend over at least two lactation periods, this in spite of the fact that it is much more difficult to conduct such long time experiments than it is to conduct those which run for a few months only. In the long time experiments the number of observations are cut down considerably because of loss of some cows due to sickness, accident, sterility, and various other causes.

The data needed are measurements of the physical relationships. What is the function which describes how milk output changes with varying quantities of feed? How much additional milk do we get for each additional pound of grain or its equivalent fed to dairy cows, and how does this rate of return change as we approach the limit of the dairy cow's ability to produce?

Under very good dairy herd management an average return of about 2.2 pounds of 4 percent milk per pound of grain, 6/ or its feed value equivalent in the production ration, may reasonably be expected. In this connection it should not be overlooked that the average return on all feed including maintenance, both during lactation period and dry period is a much lower figure, about 1.0-1.2, depending upon the size and productivity of the cow. If intensity of feeding is increased, how then do the cows respond in production? Is it correct, as some dairy technologists maintain, 7/ that there is practically a constant relationship between feed used and milk produced? That is, for every additional pound of grain the additional return will be 2.2 pounds of milk until we reach the limit of the cow's capacity, this capacity in turn being dependent upon the hereditary characteristics of the animal. When this point is reached, almost nothing further is to be gained by increased feeding according to this point of view. Additional feed is simply wasted, the additional return being next to nothing. Or is it true, as other dairy technologists maintain, that there is a more gradual change in the response of dairy cows to increased feeding? From general experience in other fields, economists have been inclined to assume that the real situation corresponds to this second assumption--that there is a gradual decline in response for each additional unit of feed until a point is reached where nothing more can be gained by heavier feeding. For economic analysis it is of considerable importance whether the first or the second point of view is the correct one. If the first situation prevails in practice, it would pay best to feed cows as closely as possible at the rate which would insure maximum production and to stick to this practice, regardless of the changes in prices of milk and feeds, as long as there remained any profit in feeding for milk production.

In order to analyze the problem in these terms, we must consider a certain period of time. In milk production, as in other types of biological production, we have to deal with a continuously changing stream of inputs and outputs. The typical lactation curve rises sharply at first, reaches a maximum soon and falls off gradually to zero in about 280 to 300 days. Feed consumption rises and falls correspondingly, although in no exact proportion. However, by cutting off suitable periods of time, for example, one lactation period or perhaps better one year, and totaling inputs and outputs for such a period, the analysis is greatly simplified.

What we want to know is whether the lactation curve is a fixed function of time, or whether it can be pressed to higher levels. How much feed does it take to do so, and do additional increases create progressively smaller responses?

6/ This applies when the grain ration contains 75 percent digestible nutrients and the substitution values of other feeds corresponds to the accepted average feed values.

7/ See for example H. Möllgaard and Aage Lund, "Om Grundtraekkene of Malkekvaegets Ernaeringslaere." 131. Beretning Fra Forsogslaboratoriet, Köbenhavn: August Bang, 1929.

These experiments are not yet completed. So far only preliminary results from the first experimental year are available. The cumulative effects of scant feeding and of heavy feeding may modify them to some degree.

The sum totals of feed intake and milk output for the entire lactation period of each of the cows in the different herds constitute our observations. Only production records of animals which have suffered real serious disturbances due to sickness or accident have been discarded. These figures have been used for determining the regression curve describing the average relationship between feed inputs and milk output after taking account of the differences in productivity of the cows. In making this analysis first for each individual station herd and then for all herds combined, we have fitted to the observations a curve of the parabolic type ($y = a + bx + cx^2$). 8/ From each experiment station about twenty observations are available for the first year. In the number one series (see fig. 1) of experiments, it is not possible on the basis of these relatively few records, to tell for any individual station whether the regression line should be a curve or a straight line. We do find, however, that when we add these observations to similar data obtained at a number of other stations, there is a difference which is statistically significant between the curve and a straight line. In the number one experiments, feeding was strictly in proportion to production.

In the series of number two experiments, (see fig. 2) where cows are fed good roughage ad libitum, there is no doubt that a curvilinear relationship prevails.

The slope of the regression curves is about the same although the level is somewhat different. Different influences are at work at some stations which give us a better milk return for feed expended than at others, but most of the differences are within the limit of experimental error and the regression curves are almost parallel. In other words, there is hardly any difference in additional returns. By making an analysis of variance we can eliminate from our results that part of the variation

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8/ The equation actually used was: $X_1 = a + b_1X_3 + b_2X_2X_3 + b_3X_2^2X_3$. This assumes that milk production is influenced jointly by quantity of feed consumed and the productivity of the cow in such a way that if the productivity of the cow is held constant, there is a curvilinear relationship between feed and milk production and if feed inputs are held constant, the relationship between productivity of the cow and quantity of milk produced is described by a straight line. X_1 = milk production (pounds of 4% fat corrected milk). X_2 = production ration (feed above maintenance ration) in pounds of digestible nutrients. X_3 = productivity of the cow, pounds of 4% fat corrected milk (production expected from past performance). a, b_1, b_2, and b_3 = constants.

RELATION OF MILK OUTPUT TO FEED INPUT AFTER TAKING ACCOUNT OF THE DIFFERENCE IN PRODUCTIVITY OF THE COWS
(EXPECTED YIELD)

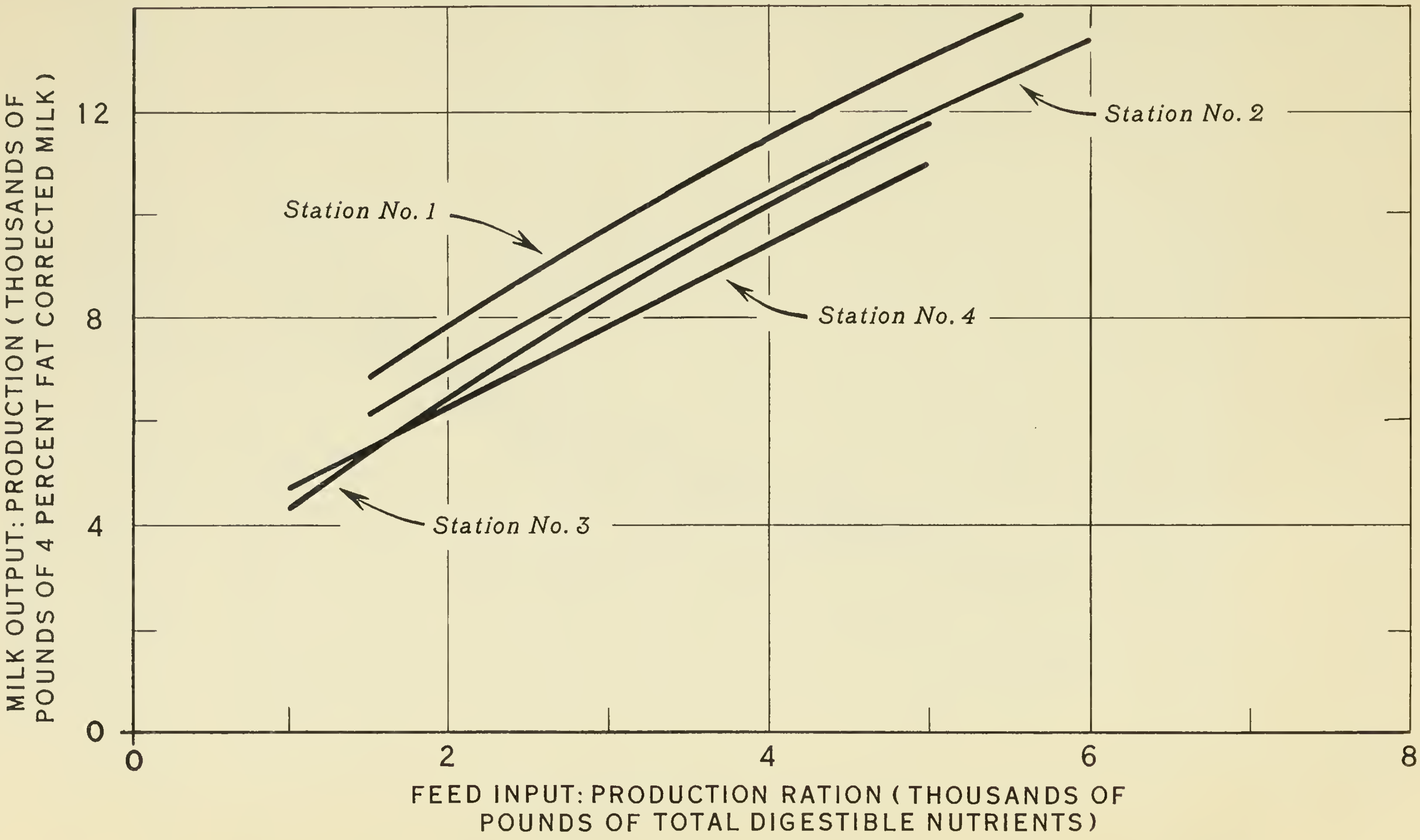

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FIGURE 1

RELATION OF MILK OUTPUT TO FEED INPUT AFTER TAKING ACCOUNT OF THE DIFFERENCE IN PRODUCTIVITY OF THE COWS
(EXPECTED YIELD)

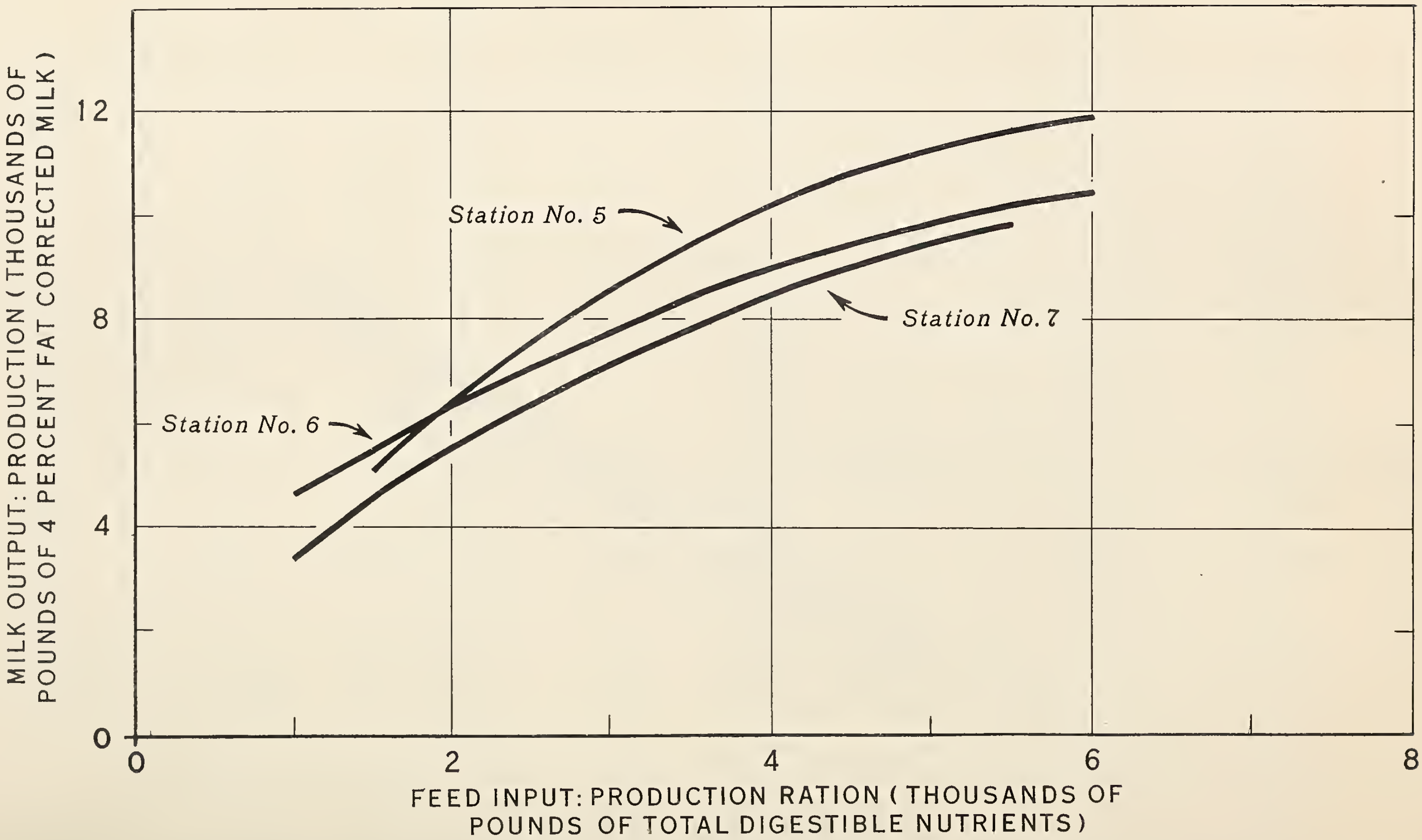

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FIGURE 2

which is due to those factors which cause differences in the level of the regression curves. We can then consolidate and average the observations for all the stations. This gives us one regression curve for all the cows on the experiment. (See fig. 3.)

We have computed our experimental error and indicated by a band of varying width around the regression curve how consistent and accurate our results are at the different levels of feeding. 9/ It will be noted that even after all our careful work we still come out with an experimental error of 5 to 6 percent in estimating production for a sixteen cow herd. This is not so large that it vitiates our results.

For individual cows the error is several times as large. It is a difficult matter to predict what the production performance of an individual cow will be. The variation from year to year is very great. As Professor Haecker says in one of his reports, "Indeed the ways of the cow are very strange; sometimes she does and sometimes she doesn't, and sometimes she does neither". However, what the practical farmer wants to know is how the average production of his herd will be changed if he goes in for heavier feeding. This information we can obtain from our curves with a fair degree of accuracy.

As shown by the results presented in the form of these curves, we have found that it is possible to influence milk production very considerably by feeding increasing quantities of feed. It has been thought that if cows in milk were fed in excess of the level necessary to maintain body weight, the cows would gain in weight. They would use a substantial part of the ration for this purpose instead of converting it into milk, thus making additional feeding a highly questionable practice from an economic point of view. We find that this actually happens to some extent. Cows do utilize some of the additional feed for gain in body weight, but in the cows of the dairy breeds with which we are working, we find that the gain in live weight is small and the increase in milk production large. The rate of increase falls off very slowly.

If these preliminary indications are verified by the analysis of the second year's results, what then will be the practical meaning of these findings? It would seem to be a matter of great practical importance that increases in the intensity of feeding beyond the level indicated by the commonly accepted feeding standards give rise to a response which is only about one half as great as has so far been assumed in the common use of the feeding standards. It is usually assumed that one pound of grain,

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9/ The method used is one suggested by Frederick V. Waugh and Richard O. Been in the article "Some Observations about the Validity of Multiple Regressions" in the Statistical Journal of the Statistical Association of the College of the City of New York, Vol. II, No. 1, January, 1939, pp. 6 to 15.

RELATION OF MILK OUTPUT TO FEED INPUT WITH MARGIN OF ERROR INDICATED

(AVERAGE RELATIONSHIP FOR COWS OF 8,000 POUNDS EXPECTED YIELD AFTER TAKING ACCOUNT OF THE DIFFERENCES IN PRODUCTIVITY OF COWS; 7 STATIONS, 129 COWS, DIFFERENCES BETWEEN STATIONS ELIMINATED)

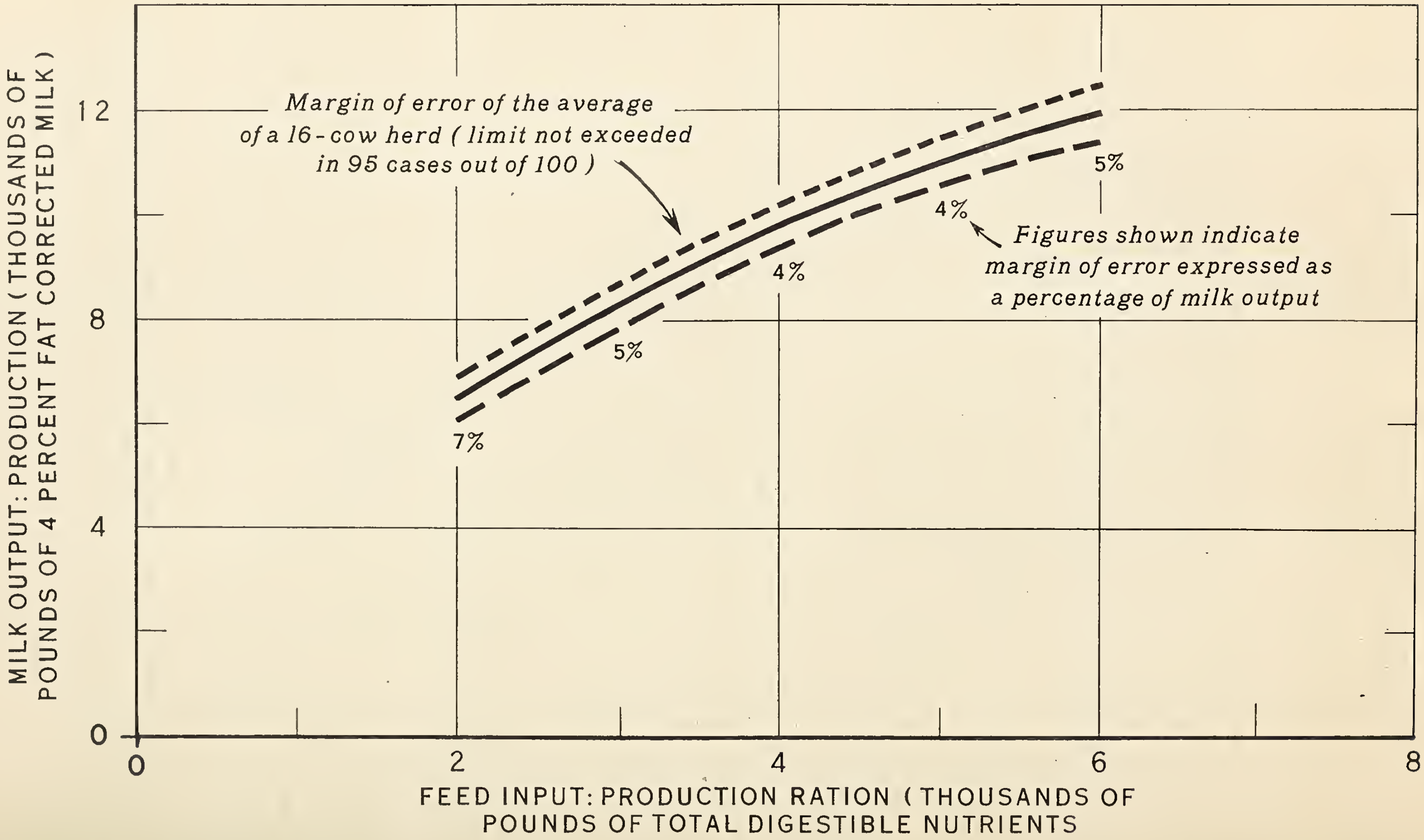

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FIGURE 3

containing 0.75 pound digestible nutrients, or its equivalent in other feeds will return about 2.2 pounds of milk containing 4 percent fat. Our experiments show that near the feeding-standard level one does obtain an average return of this magnitude for all feed consumed and all milk produced, but this rate of return cannot be applied to increases or decreases in feed intake from this level. Here the response to such changes is only about 1.0 - 1.2 pounds of 4 percent milk for each additional pound of grain or its equivalent in other feeds.

The "requirements" represent average input per unit of output and are not applicable to results obtained by increases or decreases in feeding above and below standard feeding levels in the range in which most changes made by farmers take place. The response is here only half as great. It is greater if you increase from a lower level and less if you are already feeding very heavily, and it is better for inherently high producers than for low producers. However, the average response to additional feeding is of this much lower order.

It is also important to note that although the principle of diminishing returns seems to hold good in dairy feeding, the rate of decrease in returns is very slow so long as we have not reached very heavy feeding. Within a considerable range near the level indicated by the feeding standard, the curve of diminishing returns comes close to being a straight line.

This means that there is a very considerable amount of physical elasticity in dairy feeding. With the same dairy herds it is possible to utilize larger than normal feed crops and this can be done with small loss in efficiency. This is especially true if the additional feed is in the form of grain. Similarly in a year of shortage it is possible to reduce the ration without as serious consequences to production as have so far been assumed.

Our experience also shows that very considerably increased milk supplies can be obtained in a relatively short time by raising the level of feeding if prices change so as to make such a development profitable. The input-output data enables us to determine more definitely how far it pays to go. These relationships were not unknown before, but their magnitude was not very well determined.

It will also be seen that the penalty for not hitting exactly the most profitable level of intensity is not so great because the rate of return falls off slowly. This also explains why, when milk prices permanently are much higher in some sections than in others while grain prices are not much different, farmers will make adjustment. On account of the basic response relationship, this adjustment must be great. Because the marginal rate of return falls off slowly, it pays to go much farther along the curve if there is a wide margin between milk and feed prices. The difference in intensity must be very considerable because the price advantage is not wiped out by diminishing returns until a considerably higher rate of feeding is reached. This actually seems to be what we find in practice. Dairymen in northern New England where milk prices are comparatively low do not feed nearly so heavily as do dairymen in Massachusetts and Connecticut where milk prices permanently are high. Similar differences are to be expected in the Middle West between areas adjacent to big cities and outlying areas where milk must be sold for dairy manufacturing purposes.

The economic analysis developed in production economics which applies to these problems is well known and only the more simple parts of it need be used if we restrict ourselves to an analysis of the economy of more or less heavy grain feeding. If we want to consider also important changes in the quantities of home grown roughages fed, we must take account of the economic effects of changes in the use of land for the growing of these crops and we shall then have to go into an analysis of the whole farm business in order to complete the investigation.

However, time and space do not permit us to treat these problems at the present time. These and similar problems can also better be analyzed when the full amount of data from our present investigations becomes available and the rates of return at various intensity levels continuously adhered to are more definitely established. For these reasons I have stressed those aspects of our investigations which have to do with the provision of the physical data and have given only a few indications of the ways in which these input-output data may be useful.